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EFFECT OF FIBRE TYPE ON HEAT LOSS THROUGH FABRICS

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ABSTRACT

The heat flow through thin cotton and polyester woven fabrics of similar physical properties, plus three types of knitted underwear, was measured on a guarded hot plate to determine the influence of fibre type on heat loss. Two conditions were selected - one where the fabric was wetted and allowed to dry to simulate the case where the sweat had totally wicked from the skin into the clothing on top of it and one where a warm surface was wetted to simulate sweating skin and a dry fabric placed on top of it. It was found that the fibre type has no influence on the heat loss through a dry fabric or from a wet fabric. Further, more heat was lost from the skin when water remained on it, rather than wicking to the overlying fabric. Finally, the time for a wet fabric to dry and the amount of energy required to do so depended entirely on the amount of water originally in the fabric, again independent of fibre type.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Over the past few years, "active" clothing for outdoor people has been introduced into the marketplace. The manufacturers claim that these products, be they underwear or jogging suits, do not or do absorb moisture and so they will keep an exercising person, warm, dry and comfortable. In order to sort out their claims, or otherwise, we undertook a research project to measure the heat flow through thin cotton and polyester woven fabrics of similar physical and water-holding properties (1) to determine the influence of fibre type on heat loss. In addition, we included three types of underwear. Two conditions were selected – one where the fabric was wetted and the "skin" under it was dry to simulate the case where the sweat had totally wicked into the clothing on top of it and one where a warm surface was wetted to simulate sweating skin and a dry fabric placed on top of it.

METHOD

Of the four similar woven fabrics selected, two were cotton, and two polyester, all obtained from Testfabric Inc., New Jersey. The underwear included a well-used and laundered cotton waffle weave Canadian Forces (CF) underwear, and two commercially-available knitted underwear, a polyester (Hot Chilies®) and a 5-times-laundered polypropylene (Superskins®). The pertinent physical properties of all the fabrics are given in Table 2. From an experimental point of view, it was fortunate that the commercially-available polyester knit had similar mass and thickness to one of the cotton fabrics and one of polyester fabrics.

Table 1: Pertinent properties of the fabrics used.

Fabric	Mass (g/m^2) [a]	Thickness (mm) [b]	Count (yarns/ cm or courses and wales/cm)[c]	Regain (%)[d]
Cotton sheeting	155	0.41	22x17	7.0
Cotton lawn	100	0.28	32x32	7.0
Polyester plain weave A	159	0.41	20x16	0.4
Polyester plain weave B	121	0.30	25x21	0.4
C F underwear	313	2.57	waffle knit	7.0
Polyester knit	155	0.58	10x14	0.4
Polypropy-lene knit	212	1.45	24x36	0

[a] CAN/CGSB-4.2 "Unit Mass of Fabrics" Method Number 5.1-M90.

[b] CAN/CGSB-4.2 "Fabric Thickness" Method Number 37-M87.

[c] CAN/CGSB-4.2 "Textiles - Woven Fabrics - Construction - Methods of Analysis - Part 2: Determination of Number of Threads per Unit Length (ISO 7211-2:1984) Method Number 6-M88 and "Knitted Fabric Count - Wales and Courses per Centimeter" Method Number 7-M88.

[d] CAN/CGSB-4.2 "Table of Contents, Moisture Regain Values, SI Units Used in CAN/CGSB-4.@-M and Fibre, Yarn, Fabric, Garment and Carpet Properties (Amendment No 1, March 1992)" Method Number 0-M87.

A guarded hot plate was used for the experiments. The test area has a surface of $.01m^2$ (approximately 11 cm diameter), surrounded by a 2.5 cm wide guard ring of identical area. The surface temperatures of both were set at 30°C. The plate and guard ring were covered with a thin stretchable and wettable fabric. Fabric samples were cut to cover the entire hot plate.

In the first set of experiments, the fabrics were wetted out by soaking in water, squeezing the excess water out by hand and blotting on paper towels. This was acceptable since the amount of water left in the sample was not critical to the experiment. The sample was weighed to determine the amount of water in it and then placed on the dry 30°C surface and allowed to dry.

In the second set of experiments, drops of distilled water from a full 2.5 ml hypodermic needle were placed in decreasing circles onto the test surface (but not onto the guard ring). The drops of water wicked into the surface of the fabric, spreading to cover the hot plate only. The hypodermic needle technique was used to ensure that the same amount of water was placed on the plate for each experiment. A dry sample of fabric was then placed on top of the plate and the water allowed to evaporate from the hot plate surface through the fabric. In both experiments, the heat flux was recorded and the heat flux vs time to dry (i.e. the total area under the curve) calculated and corrected for the heat loss from the bare plate alone.

A computer took three readings a minute from the hot plate. To make the data manageable, the readings were averaged and recorded only when slight deviations in temperature occurred. For our purposes, this was satisfactory, but it should be noted that the results can be out by a minute or two.

All experiments were done in a textile conditioning room (20°C, 65% relative humidity).

RESULTS AND DISCUSSION

Although "seconds" is the SI unit, "minutes " is retained throughout the results since it is easier to understand.

Two types of drying curves for the wet fabrics were obtained and are shown in Figure 1. The curve on the left is typical of the polyester fabrics and the curve on the right of the cotton fabrics. Likewise, in the dry fabrics on the wet surface experiments, a curve similar to the one on the right was obtained when some of the water wicked from the wet plate to the cotton underwear above. It is well known that this "tailing off" is the energy required to evaporate chemically-bonded water from the cotton fibre. (The spikes are due to the increased heat flux which occurs when room temperature wet samples are placed on the heated plate.)

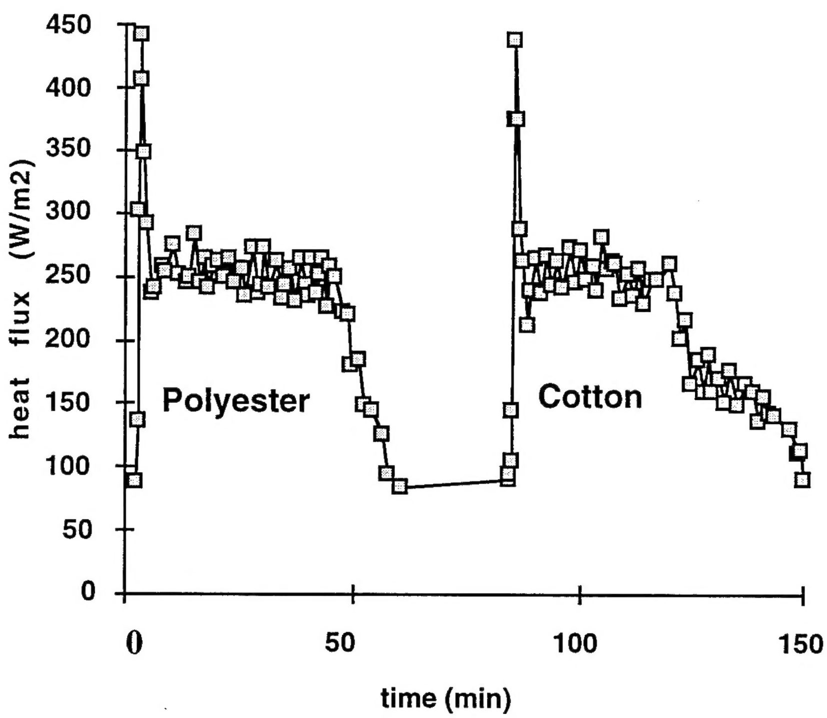

Figure 1: Typical drying curves of polyester and cotton fabrics.

The numerical results for both experiments are given in Table 2, and for ease of understanding, the first three columns will be illustrated graphically.

Table 2: Columns 2 to 4 give the results of the experiment in which the fabric was wetted and placed on the dry plate. Column 5 gives the amount of energy required to evaporate 2.5g of water from the plate.

Fabric	Initial amount of water in fabric (g)	Time to dry (min)	Heat flux x time to dry W•min/ m^2	Heat flux x time for 2.5g water to evaporate W•min/m^2
Cotton A (sheeting)	3.2 2.9	53 57	3464 2025	7855
Cotton B (lawn)	1.7 1.3	28 25	1574 1347	8160
Polyester plain weave A	1.3 0.6 2.6	24 11 50	1697 370 2855	7410
Polyester plain weave B	1.1 2.6	22 50	1454 2268	8186
				Average = 7903 CV [a] = 4%
Polyester knit	3.0 1.9	46 27	3802 2375	7915
Polypropylene knit	5.6	107	4373	6443
CF underwear	13.7	217	10891	5179
Plate alone	2.5	47		9300

CV [a] = coefficient of variation

It has been shown previously (2) that the time for a fabric to dry in a textile conditioning room is independent of fibre type, but instead is linearly related to the amount of water in the sample. Likewise, this experiment has shown this to also be the case (Figure 2a and 2b).

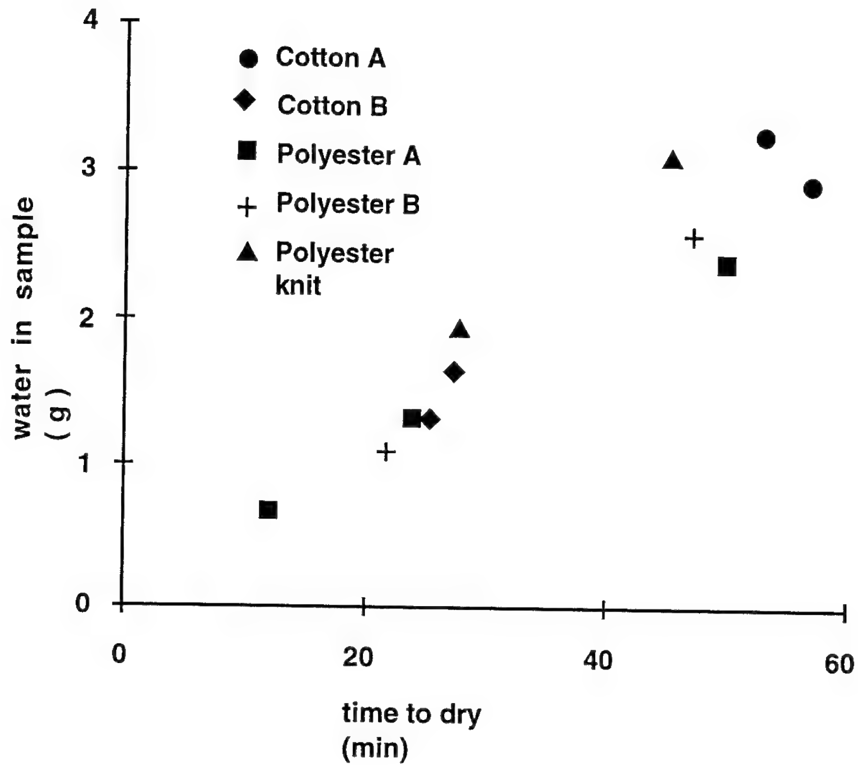

Figure 2a. This shows that the time for a fabric to dry depends solely on how much water is in it initially, not whether its fibre content is cotton or polyester.

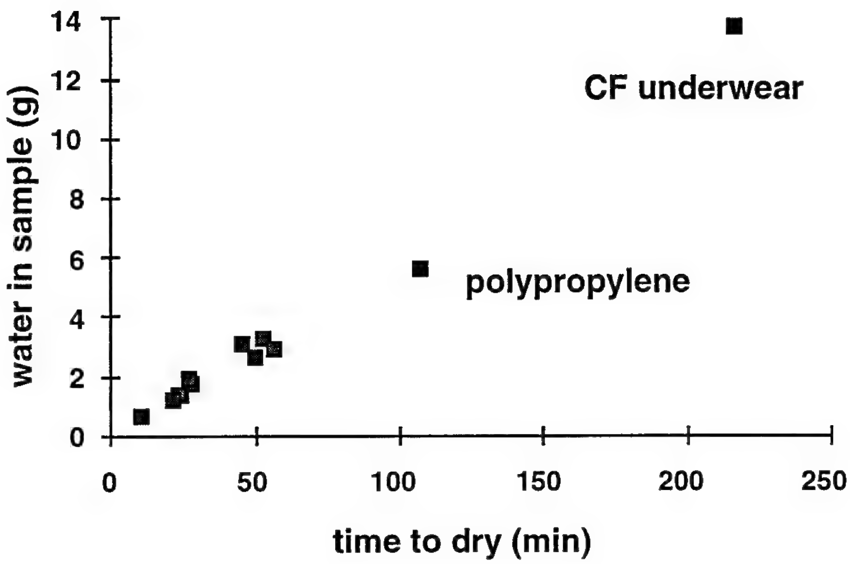

Figure 2b: This Figure extends the time axis to include the experimental values for the polypropylene and CF underwear to Figure 2a, showing that the more water initially in the sample, the longer it takes to dry.

Finally, the amount of water originally in the fabric is linearly related to the heat flux times time or energy required to evaporate the water (Figure 3).

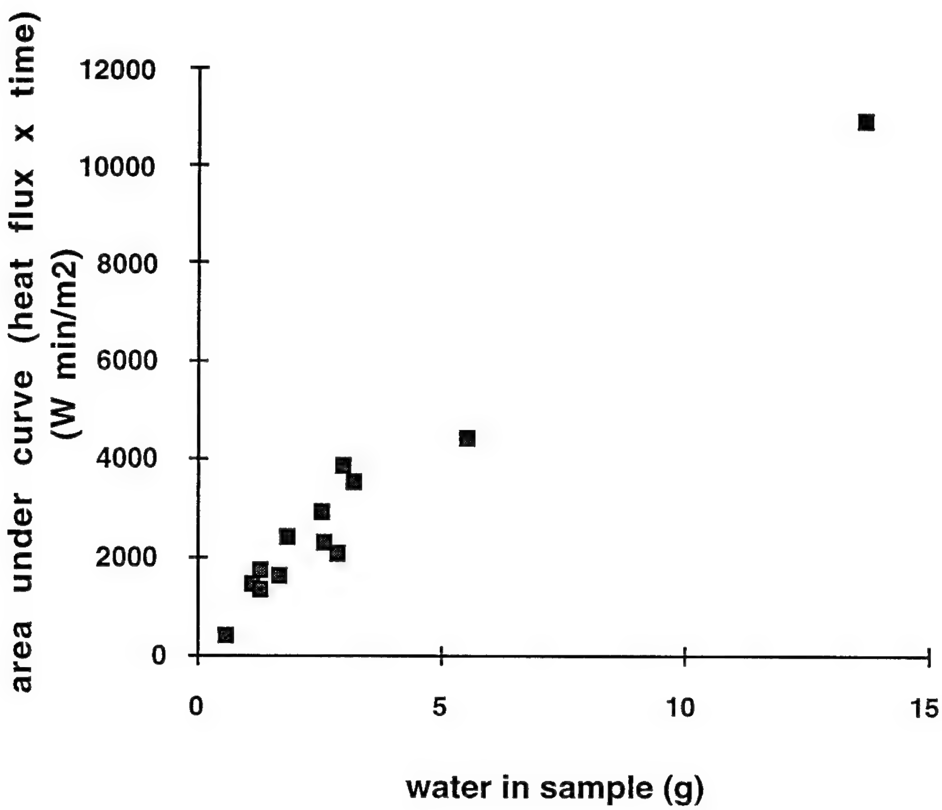

Figure 3: The energy required to evaporate water from wet fabrics is linearly related to the amount of water initially in the fabric.

In the second experiment where 2.5g of water was placed on the plate, it was observed that a small amount of water wicked from the wet surface into the cotton sheeting and a large amount of water (1g) into the CF underwear. Despite the advertisements of the special wicking abilities, no water wicked from the plate into the polyester or polypropylene underwear. In fact, in the first experiment, the laundered polypropylene underwear was extremely difficult to wet, the water-attracting finish obviously having been removed in laundering.

Going back to Table 2, it can be seen that the amount of energy required to evaporate 2.5g water from the bare wet surface (or the skin) is 9300 W•min/m^2. The amount of energy required to evaporate 2.5g from the wet plate through all the dry woven fabrics is the same within experimental limits, and again is independent of fibre type, with the average being 7900 W•min/m^2. Note that this is the same amount of energy required to evaporate 2.5g of water through the polyester knit underwear.

In all cases, some of the heat to evaporate the water on the plate would have come from the surrounding air: the thicker the fabric, the more heat coming from the air. It was observed that the polypropylene sample would not lie flat on the plate with pockets of air randomly occurring across it, effectively increasing its thickness. This would account for its lower heat loss from the plate (6443 W•min/m^2). The CF underwear had the least heat loss from the plate (5179 W•min/m^2). In addition to it being the thickest sample, about a gram of water had wicked into it from the wetted plate. Therefore, more energy would have come from the surrounding air to evaporate the total amount of water than would have been the case with the other, thinner, samples.

Eliminating the unit of area from the above energy values, we find that evaporating 2.5g of water from a bare plate requires 5.58×10^3 W•s and through the dry fabrics requires 4.74×10^3 W•s. These values compare favourably with the theoretical amount of energy of 6.08×10^3 W•s which is required to evaporate 2.5g of water.

To compare the two experiments, the amount of energy required to evaporate 2.5g from a wet fabric on a dry plate (rather than a dry fabric on a wet plate) was interpolated from Figure 3 and is about 6400 W•min/m^2. This is about a third less than the energy which is required to evaporate the same amount of water from the bare plate, or the skin. This is logical since a portion of the energy to evaporate the water from the wet fabric is coming from the surrounding air.

Therefore, for maximum heat loss from the skin, as would occur in hot weather conditions or at high activity levels, it would be better for the water (sweat) to evaporate from the skin and not wick into the fabric (clothing) above it. In contrast, to keep one warm in cold weather, one would want less heat to be supplied by the body to evaporate sweat. In this case, it would be better if sweat wicked into and evaporated from the layer above the skin. However, for minimal heat loss, the amount of water taken up by this layer should be low so that it will dry quickly and require low amounts of energy.

CONCLUSIONS

Under the two sets of experimental conditions, the fibre type has no influence on the heat loss through a dry fabric or from a wet fabric. More heat is lost from the skin if it remains wet. If a significant amount of water wicks from a wet surface into an overlying dry fabric, then the heat loss from the skin is reduced. The least amount of heat is lost from the skin if all the sweat wicks into the fabric layer above it.

The time for a fabric to dry and the amount of energy required to do so depend entirely on the amount of water originally in the fabric.

It is noted that in these experiments, the polyester knit (Hot Chilies®) and the polypropylene knit (Superskins®) are indistinguishable from the woven polyester and cotton fabrics. Thus, scientifically, the magical claims for these underwear products are unsubstantiated.

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